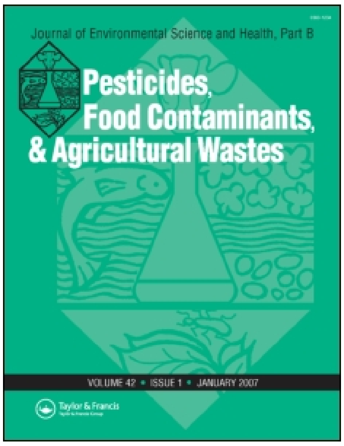

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Biomass and nutrient concentration of sweet corn roots and shoots under organic amendments application

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Two field experiments were conducted at the Waimanalo research station on the island of O'ahu, Hawaii to study the effect of chicken (CM) and dairy (DM) manures on biomass and nutrient concentration in sweet corn roots and shoots. Sweet corn (super sweet 10, *Zea Mays* L. subsp. *mays*) was grown for two consecutive growing seasons under four rates of application (0, 168, 337, and 672 kg ha^{-1} total N equivalent) and one time (OTA) or two time (TTA) applications of organic manure types and rates. There were significant effects of types, rates, and number of manure applications on dry biomass and macro- and micro-nutrient concentration in roots and shoots tissues. Results of root tissue indicated a significant accumulation of N and C under CM and DM treatments compared with the control treatment. Manure application rates significantly increased the accumulation of N and C in root tissue. Dry weight of roots and shoots and both macro- and micro-nutrient contents in the plant tissues significantly increased under TTA treatment compared with OTA treatment. There was a significant correlation ($r^2 = 0.46$ to 0.81) between root biomass, macro-, and micro-nutrient contents during both growing seasons. The results of the study indicates that amending soils with CM at the highest application rate provided the best crop performance in terms of root and shoot biomass, crop N, C, and other macro- and micro-nutrients.

Keywords: Animal manure; macro- and micro-nutrient contents; nutrient uptake; sweet corn growth.

Introduction

Sweet corn (*Zea Mays* L. subsp. *mays*) has become one of the most popular and economically important crops in the world.[1,2] Its production in Hawaii is expected to increase as much as 57% in harvested acreage in the coming years.[3] Sweet corn requires high amount of nutrients and fertile soil for high yield, and can be grown in a wide variety of soils if they are naturally fertile or are made fertile with appropriate fertilizer and/or organic manure.[4]

In general, soils rarely have sufficient N for crops to produce their potential yield. Therefore, farmers tend to apply soil amendments (commercial fertilizer or manure amendments) that are rich in nutrient, i.e. N, P, and K to ensure increased crop productivity.[5,6] Currently, corn growers apply N in the range of 150 to 200 kg ha^{-1} and the application amount depends on initial soil nutrient status, soil type, and climatic conditions.[7,8] However, N application based on yield goals prior to planting may result in over or under application of N due to weather induced variation in yield potential and year–to–year soil mineralization.[9,10] To achieve an optimal corn yield, animal manures also used as soil amendments as these manures contain macro- and micro-nutrients that may enhance plant growth and plant nutrient content.[11,12]

Depending on environmental conditions, inappropriate application of animal manures could pose environmental problems including the contamination of ground and surface water even while improving soil and crop productivity.[13,14] The application of manure to soils could cause alteration of soil pH, as the soil microenvironment changes due to manure application. In addition, the resulting interactions with organic matter could increase or decrease the availability of nutrients, and may result in direct toxic effects on the plant to the level that may pose a health hazard to consumers.[15–18]

Addition of organic matter to soil may improve soil structure, aeration, soil water holding capacity, and water

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infiltration,[19,20] and is considered an agronomically feasible and economically viable manure disposal option.[21] Many Hawaiian farmers use animal manure as a soil amendment to meet the needs of their crops, i.e., sweet corn.[4]

In Hawaii, cattle population increased by 5% over the past 5 years (153,000 in 2002 to 161,000 in 2007.[3] Management of livestock manure and effluent are a serious concern for the farmers in Hawaii due to limited land availability for disposal. There are farms and some commercial industries in Hawaii marketing animal excreta as manure or compost for use on farmland.

Antibiotics and pharmaceuticals exist in animal manures because they are administrated to animal for treatments of infectious diseases and mixed with feed supplement for enhanced animal's growth, respectively.[22−25] Most of these antibiotics appear in animals' urine and feces due to their poor absorption by animal guts.[24] Plants and crops grown on soils amended with such organic manures may uptake these antibiotics and pharmaceuticals which would pose a hazardous risk to human and animals if they use these plants or crops as feed or food.[22−25]

Studies conducted by a number of investigators on the effects of different organic and inorganic fertilizers and/or mixture of both under different rates of application on crop productivity and plant nutrient content showed that the additions of manure amendments significantly improved plants growth and increased the macro- and micro-nutrient contents in plants tissue.[26−30] It is important to have a clear understanding about the role of organic manure application on corn dry biomass production and nutrient uptake, translocation, and distribution within the plant. These are important factors for the development of management strategies to optimize nutrient uptake efficiency.[31] Management practices, including rate, type, and method of fertilization, can influence the dry matter and the accumulation of nutrients in plants.[32,33]

Available literature regarding the interactions of major production contributing factors, i.e., fertilizer N supply, soil, weather, and irrigation for optimizing corn production was emphasized by Derby et al.[34] and Mulvaney et al.[7] in field studies in the corn-belt of the United State. However, information is inadequate regarding the role of animal manures for optimizing sweet corn production in agricultural production areas in Hawaii with its diverse soils and tropical climatic conditions characterized by frequent and high rainfall pattern, which significantly affect the nutrient dynamics in soils and plants. Research is required to obtain a clear understanding of nutrient dynamics (release, retention, transport, and availability to crops) in soil receiving animal manures under tropical climatic conditions of Hawaii. Therefore, the objective of this study was to evaluate the effect of types, rates, and number of animal organic manure (CM-chicken manure; DM-dairy manure) applications on (i) sweet corn root and shoot dry weights, (ii) macro- and micro-nutrient concentration in crop roots and shoots, and (iii) the correlation between the studied variables for two consecutive growing seasons.

Materials and methods

Study area

This study was undertaken at the Waimanalo Agricultural Research station of the University of Hawaii (21° 20′ 15″ N, 157° 43′ 30″ W). Soil at the study site is classified as Waialua silty clay (very-fine, mixed, superactive, isohyperthermic Pachic Haplustolls).[35] This soil is generally found in basins and on alluvial fans (primary agricultural areas) on the islands of Maui and Oahu and was formed on alluvium derived from igneous rocks. The long-term average precipitation at Waimanalo is 1132 mm yr^{-1}, most of which occurs between November to April.[36] Selected properties of this soil are presented in Table 1.[35]

Experimental design

The experimental design for this study was a randomized complete block design replicated three times for the first growing season, where manure types (chicken and dairy) and rates of application (0, 168, 336, 672 kg ha^{-1} total N equivalent) were randomly distributed in each block. Nutrient contents of chicken and dairy manures used for the two growing seasons are presented in Table 2. An experimental design for the second growing season was factorial within strip plot design replicated three times. The sizes of plots were 1.8 m × 18.2 m and 1.8 m × 9.1 m for the first and second growing seasons, respectively. In the second growing season, the plots used in the first growing season were split in half. One-half of each plot received additional manure to make up for the mineralized portion of the manure during the first growing season. These plots were the two time application (TTA) treatments of the experiment. However, the other half did not receive any additional manure during the second growing season and served as one time application (OTA) treatment. The manure was incorporated in the soil to 15 cm depth.

Table 1. Selected properties of soils at Waimanalo, HI (Waialua clay varient).

Depth (cm)	% *Sand*	% *Silt*	% *Clay*	% *OC*	$K^{\dagger}_{sat}$ *m d*$^{-1}$	θ_{aw} *cm*^{3} *cm*$^{-3}$	ρ_b *g cm*$^{-3}$	*pH* ‡
0–38	11.2	42.9	45.9	1.94	2.44	0.13	1.20	6.68
38–91	11.4	43.8	44.8	0.80	2.44	0.14	1.10	—

†Saturated hydraulic conductivity; θ_{aw} available water content; OC organic carbon; ρ_b bulk density, ‡pH at 1:1 ratio H_2O.

Table 2. Nutrient contents of the chicken and dairy manures used in this experiment as per analysis at the beginning of first and second growing seasons.

	%							$\mu g\ g^{-1}$				
	N	*C*	*P*	*K*	*Ca*	*Mg*	*Na*	*Fe*	*Mn*	*Zn*	*Cu*	*B*
First growing season												
Chicken	3.01	21.52	1.47	1.97	14.26	0.75	0.40	209	967	397	43	30
Dairy	1.84	15.09	0.49	1.88	2.05	1.02	0.52	4317	330	123	191	44.66
Second growing season												
Chicken	2.21	19.34	1.82	1.31	10.57	0.62	0.21	2286	669	302	28.68	36.45
Dairy	2.46	11.66	1.04	4.16	2.89	1.54	0.91	13760	740	215	153	132

Planting, harvesting, and nutrient analysis of roots and shoots

Sweet corn was planted in the manure–amended plots that were irrigated with a drip irrigation system. Each plot had four rows of the crop with a plant population between 9,000 to 10,000 plants ha^{-1}. Manures were applied on April 25 and November 25, 2006 for first and second seasons, respectively. Corn seeds were sown on June 6 and December 15, 2006 and allowed to grow until harvesting on August 24, 2006 and March 20, 2007 for the two growing seasons, respectively.

At the harvest, one random plant from each treatment plot was selected. During the first growing season, only roots were sampled, while in the second growing season both roots and shoots were sampled for analysis. The whole plants were sampled using a large shovel with the maximum of plant root system and securely placed in separate plastic bags and taken to the laboratory for sample preparation. The roots samples were carefully cleaned and washed with water. Both the roots and shoots samples were placed in paper bags then into the oven (Fisher IsoTemp oven, Fisher Scientific, 200 series) at 70°C for 72 h. The oven-dried roots and shoots were grinded to pass through 20-mesh (841 μm) sieve. The samples were then dry-ashed in a muffle furnace at 550°C for 6 h and dissolved in 20 mL of 1 *M* HNO_3.[37] The concentrations of macro- and micro-nutrients were determined by Inductively Coupled Plasma Optical Emission Spectro-photometry (ICP-OES). Standard reference plant samples (from National Institute of Standards and Technology) were used to check and confirm the analytical quality of ICP-OES.

Statistical analysis

SAS program version 9.1[38] was used to conduct analysis of variance (ANOVA) on the collected data. Duncan's multiple range test was performed on the significant results. Simple correlation test between the studied variables was performed to identify the relationships among selected variables.

Results and discussion

Results of the analysis of variance

A summary of the analysis of variance (ANOVA) of the experimental treatments (types, rates, and the number of manure applications) on the observed parameters (i.e., plant root dry weight and the concentration of macro- and micro-nutrients) in terms of significance levels is presented in Tables 3 through 5. The results in Table 3 presents the ANOVA of these parameters and treatments studied during the first growing season. There was a highly significant effect ($P < 0.01$) of type and rate of manure application on the dry root weight and on the concentration of carbon (C),

Table 3. Analysis of variance (ANOVA) table for root dry weight and the concentration of macro- and micro-nutrients in the plant roots of the first growing season crop.

			Macro-nutrient					Micro-nutrient							
SOV	*DF*	*Root dry weight*	*N*	*C*	*P*	*Ca*	*Mg*	*Zn*	*Mn*	*Fe*	*Cu*	*Cd*	*Cr*	*Ni*	*Pb*
Block	2														
Type	2	**	*	**	**	NS	NS	**	**	*	NS	NS	*	nd	NS
Rate	3	**	**	**	**	NS	NS	**	**	NS	*	NS	*	nd	NS
T × R	6	*	*	*	*	NS	NS	NS	NS	NS	NS	NS	NS	nd	NS
Err	10														
Total	23														

T = manure type, R = manure rate, NS = not significant, nd = non-detectable. *Significant. **Highly significant. SOV = source of variation. DF = degree of freedom.

Table 4. Analysis of variance (ANOVA) table for root dry weight, root macro- and micro-nutrient contents in the second growing season.

			Macro-nutrient			*Micro-nutrient*							
SOV	*DF*	*Root dry weight*	*P*	*Ca*	*Mg*	*Zn*	*Mn*	*Fe*	*Cu*	*Cd*	*Cr*	*Ni*	*Pb*
Block	2												
No.App.	1	**	*	**	**	**	**	**	**	**	**	NS	NS
Err (a)	2												
Type	2	**	**	**	**	**	NS	**	**	NS	NS	*	NS
Rate	3	**	*	*	**	NS	NS	**	**	NS	*	*	**
T × R	6	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Err (b)	10												
N × T	2	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
N × R	3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N × T × R	6	NS	*	NS	NS	NS	NS	*	NS	NS	NS	NS	NS
Err (c)	10												
Total	47												

T = manure type, R = manure rate, NS = not significant, nd = non-detectable, SOV = source of variation, DF = degree of freedom. *Significant. **Highly significant.

phosphorous (P), zinc (Zn), and Manganese (Mn). Type of manure had a significant effect ($P < 0.05$) on root content of iron (Fe) and Chromium (Cr) while the rate of manure application had a significant effect ($P < 0.05$) on the concentration of Cu and Cr. The interaction of manure type and rate was significant ($P < 0.05$) for dry weight of roots as well as for concentration of C, N, and P. However, there was no significant effect of either type or rate of manure application on the concentration of the rest of micro-nutrients studied and on that of Ca and Mg.

The results of the analysis of variance (ANOVA) of the second growing season include additional variables; the number of manure applications as consequence of two time application of manures to one-half of each plot during this cropping period. Significance levels in the ANOVA table (Table 4) shows that the number of applications had a highly significant effect ($P < 0.01$) on dry weight of plant roots and the concentration of macro- and micro-nutrients in the root tissue with the exception of nickel (Ni) and lead (Pb). Types of manure application had a significant effect (either $P < 0.05$ or $P < 0.01$) on root dry weight and all nutrient contents except Mn, Cd, Cr, and Pb. Similarly, the rate of manure application had a significant effect (either $P < 0.05$ or $P < 0.01$) on all the root tissue parameters evaluated with the exception of Zn, Mn, and Cd. With the exception of P and Fe concentration in root tissue ($P < 0.05$), all other parameters showed non significant effect due to interaction of types, rates, and number of manure applications.

Similar to the root tissue results, all the parameters measured in the shoot tissues showed significant effects (either $P < 0.05$ or $P < 0.01$) due to the number of manure applications with the exception of P and Cd (Table 5). Type

Table 5. Analysis of variance (ANOVA) table for shoot dry weight, macro- and micro-nutrient contents in the second growing season.

			Macronutrient			*Micronutrient*							
SOV	*DF*	*Shoot dry weight*	*P*	*Ca*	*Mg*	*Zn*	*Mn*	*Fe*	*Cu*	*Cd*	*Cr*	*Ni*	*Pb*
Block	2												
No. App.	1	**	NS	*	**	**	*	**	**	NS	*	**	*
Err (a)	2												
Type	2	**	*	**	NS	NS	NS	NS	**	NS	NS	NS	**
Rate	3	**	**	NS	NS	NS	NS	NS	*	NS	NS	*	**
TxR	6	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Err (b)	7												
NxT	2	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
NxR	3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NxTxR	6	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Err (c)	10												
Total	47												

T = manure type, R = manure rate, NS = not significant, nd = non-detectable, SOV = source of variation, DF = degree of freedom. *Significant. **Highly significant.

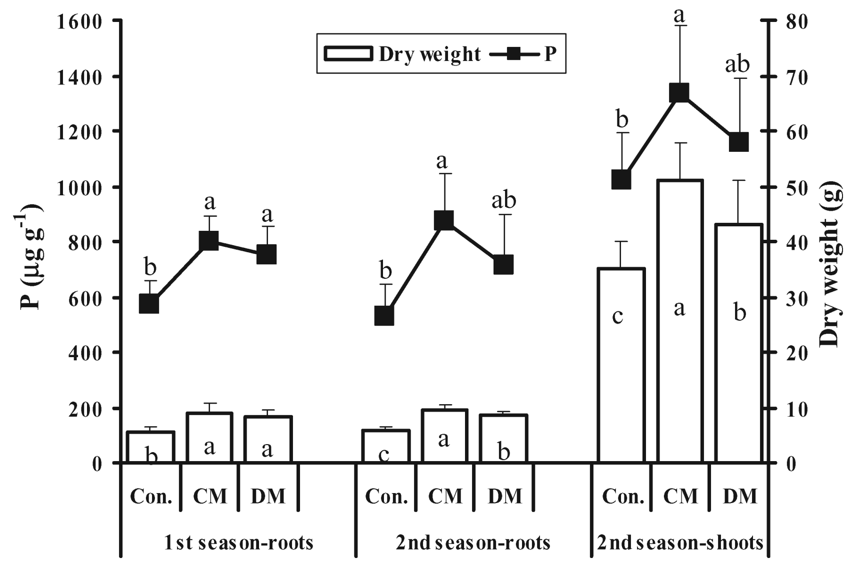

Fig. 1. Plant root and shoot dry weight (g) and P content (μg g^{-1}) for the tested manure types and growing seasons.

of manure significantly ($P < 0.01$ or $P < 0.05$) affected dry shoot weight and nutrient contents including P, Ca, Cu and Pb. There was a highly significant ($P < 0.01$) effect of the rate of manure application on shoot dry weight and the concentration of P and Pb. The rate of manure application also significantly ($P < 0.05$) affected Cu and Ni concentration in the shoot tissues. A highly significant ($P < 0.01$) effect of the interactions between the number and type of manure application was observed on P and Pb concentrations only whereas a significant effect ($P < 0.05$) of the interaction of number, type and rate of manure application was observed on P concentration only.

Effect of manure type

Biomass of roots and shoots

The biomass of roots on dry weight basis in CM and DM treatments was significantly different from that in the control treatment. There was no significant difference in the root biomass of CM and DM treatments (Fig. 1). The highest mean dry shoot weight was recorded in CM treatments, which was significantly different from that recorded in DM and control treatments. Effect of manure type on shoot biomass decreased in the following order: CM > DM > Control. The significant increase in sweet corn shoots biomass under the application of organic amendments compared to the control treatment was a good indicator for increased forage quantity for animal production use.[4,25]

Macronutrient contents

In the case of roots, in the first growing season, there was no significant difference between CM and DM for the concentrations of P, Ca, and Mg in plant shoot and root tissues. The concentrations of P (Fig. 1) and Mg (Fig. 2) in both CM and DM treatments were significantly different compared to the control treatment. The percent difference between CM and DM compared to the control treatment were 40 and 31% for P and 52 and 38% for Mg, respectively. The Ca concentration was higher for CM and DM treatment compared to control treatment, but the difference did not reach a significant level, although the Ca concentrations in the root tissues of CM and DM treatments were 25 and 11%, respectively, larger as compared to that in the control treatment (Fig. 2).

During the second growing season, the macronutrient contents in plant roots followed the same trend as that of the first growing season, which increased due to the application of manure amendments compared to the control treatment. The CM and DM treatment resulted in significantly higher concentrations of P, Ca, and Mg compared to the control treatment. However, the differences in macronutrient concentration of plant tissues of CM and DM treatments were not statistically significant. The nutrient concentrations in shoots for CM and DM treatments were 34 and 65% for P, 67 and 40% for Ca, and 25 and 41% for Mg, respectively higher than that in the control treatment. During the same growing season, the plant shoots concentration in CM and DM treatments were 31 and 14% for P; 34 and 20% for Ca; and 20 and 18% for Mg, respectively higher as compared with control treatment.

Figure 3 shows the effect of types of manure on C and N content in corn root tissue for the first growing season and the test of significance determined by Duncan's Multiple Range tests. Significant effect of types of manure on C and N was clearly evident when the plants were grown in plots treated with both CM and DM. There was no significant difference between CM and DM in the sweet corn roots (Fig. 3). The results demonstrated that N content in corn

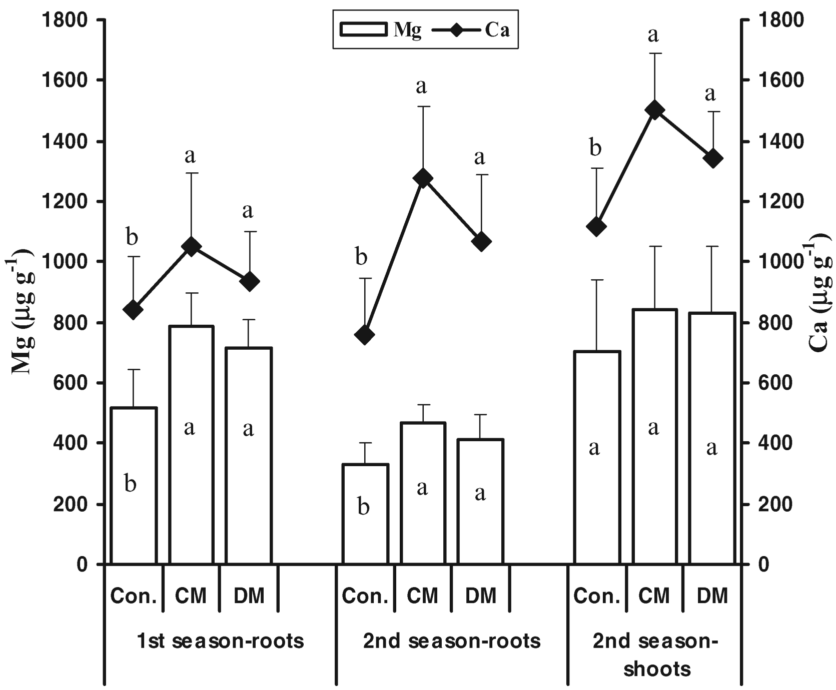

Fig. 2. Plant root and shoot dry weight (g) and Ca, Mg contents (μg g^{-1}) for the tested manure types and growing seasons.

root tissue increased by 75 and 76% for corn grown in soils amended with CM or DM, respectively. The corresponding percentage increases of C in corn root tissues were 25 and 20% for CM and DM, respectively compared to the control treatment. The increase of root tissue C and N content for corn plants grown in CM and DM were not significantly different. However, the observed difference for C was quite greater than that of N. These results might be related to the fact that application of both manures were based on the total N equivalent. Also, the high response of C to the type of manure followed the same trend observed for N. This observation was clearly supported by the significant correlation ($r^2 = 0.70$) between N and C concentrations in plants roots (Table 6).

Micronutrient contents

The application of CM and DM had a significant effect on micronutrient concentrations in plant roots and shoots, except for Ni (Table 7). During the first growing season, root tissue of the plants grown under CM had a higher content than Mn, Cd and Cr, while those grown under DM had a higher content than the rest of the other micronutrients. There was no statistically significant difference between

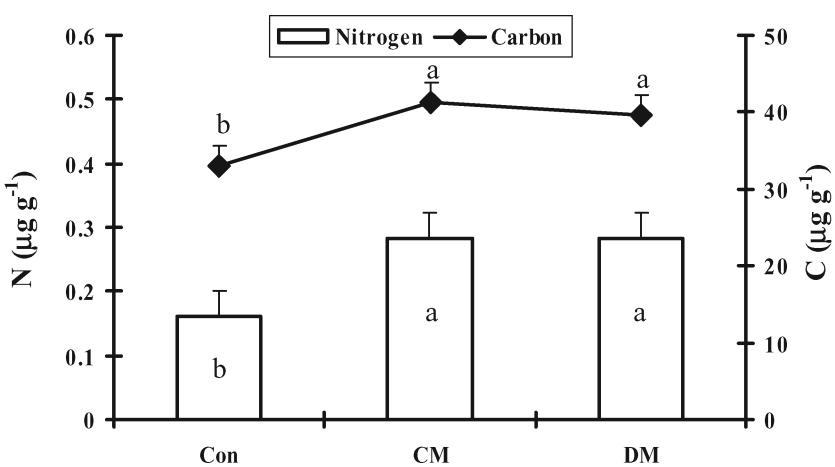

Fig. 3. Plant root and shoot dry weight (g) and N, C content (μg g^{-1}) for the tested manure types and first growing seasons.

Table 6. Correlation coefficients for dry weight, and roots content of macro and micronutrients at the harvest of first growing season.

	N	*C*	*P*	*Ca*	*Mg*	*Zn*	*Mn*	*Fe*	*Cu*	*Cd*	*Cr*	*Pb*
Dry	0.69^{**}	0.81^{**}	0.72^{**}	0.48^{*}	0.47^{*}	0.73^{**}	0.78^{**}	0.47^{*}	0.37^{NS}	0.46^{*}	0.65^{**}	0.57^{**}
N		0.70^{**}	0.67^{**}	0.38^{NS}	0.31^{NS}	0.73^{**}	0.54^{*}	0.31^{NS}	0.45^{*}	0.51^{*}	0.39^{*}	0.57^{**}
C			0.81^{**}	0.55^{**}	0.45^{*}	0.64^{**}	0.70^{**}	0.36^{NS}	0.29^{NS}	0.47^{*}	0.56^{**}	0.50^{*}
P				0.69^{**}	0.58^{**}	0.57^{**}	0.64^{**}	0.44^{*}	0.42^{NS}	0.47^{*}	0.52^{**}	0.40^{NS}
Ca					0.45^{*}	0.44^{*}	0.56^{**}	0.55^{**}	0.33^{NS}	0.18^{NS}	0.66^{**}	-0.04^{NS}
Mg						0.42^{NS}	0.67^{**}	0.34^{NS}	0.64^{**}	-0.23^{NS}	0.48^{*}	0.17^{NS}
Zn							0.61^{**}	0.36^{NS}	0.56^{**}	0.19^{NS}	0.59^{**}	0.39^{NS}
Mn								0.65^{**}	0.45^{*}	0.23^{NS}	0.67^{**}	0.19^{NS}
Fe									0.25^{NS}	0.28^{NS}	0.59^{**}	0.19^{NS}
Cu										-0.22^{NS}	0.49^{*}	0.18^{NS}
Cd											0.14^{NS}	0.51^{*}
Cr												0.22^{NS}

NS, *, ** = Not significant, significant, and highly significant, respectively.

CM and DM on the concentration of Zn, Cr, Cu, Cd, Ni and Pb. During the second growing season, micronutrients in roots followed the same trend as that of first growing season. Micronutrient concentrations in shoots showed a different response and the results did not follow the trend shown for roots. The concentrations of Zn and Mn were higher in shoot tissues of sweet corn grown under control treatment compared to that of CM and DM treatments, but the difference for Zn did not reach a significant level. The highest concentrations of Cr, Ni and Pb were in the shoots of CM treatment. Plant tissues of DM treatment showed the highest concentration for Fe, Cu, and Cd while the lowest concentrations where observed for Cr and Ni. The difference in manure types and their elemental concentrations (Table 2) could explain the observed results since these differences would have had a substantial effect on the availability of these nutrients in soil, and their content in roots and shoots. Our results agreed with the findings of previous studies.[11,18,26–30] Also, soil pH of manure- amended soils did not reveal any significant changes (not reported). Therefore, no substantial changes in the availability of soil micronutrients were expected. A similar observation was noted by Epstein and Bloom[39] with respect to soil pH and micronutrient availability for plants in manure-amended soils.

Effect of manure rate of application

Biomass of roots and shoots

There was a significant increase in root and shoot dry weights with increasing the manure application rate (Fig. 4). For low and medium application rates, the root and shoot dry weights were not statistically different from each other during the two growing seasons. These results might be related to the increase in plant growth as a response to the increase the application rate. Irshad et al.[11] reported

Table 7. Effect of type of manure application on micronutrients concentration in roots and shoots at the harvest of first and second growing seasons.

Type of application	*First growing season, root micronutrient content ($\mu g\ g^{-1}$)*							
	Zn	*Mn*	*Fe*	*Cu*	*Cd*	*Cr*	*Ni*	*Pb*
Control	12.7^{b†}	45.2^{c}	1237^{b}	28.6^{a}	0.05^{a}	10.9^{b}	nd‡	0.47^{a}
CM	18.3^{a}	82.5^{a}	1250^{b}	32.8^{a}	0.11^{a}	16.7^{a}	nd	0.70^{a}
DM	19.4^{a}	62.7^{b}	1851^{a}	36.5^{a}	0.09^{a}	12.8^{ab}	nd	0.72^{a}
	Second growing season, root micronutrient content							
Control	9.4^{b}	53.2^{b}	564^{b}	4.5^{c}	0.070^{a}	6.5^{a}	13.8^{b}	0.47^{b}
CM	10.5^{ab}	76.1^{ab}	904^{a}	5.7^{b}	0.075^{a}	7.9^{a}	16.3^{ab}	0.69^{a}
DM	12.2^{a}	95.4^{a}	992^{a}	7.2^{a}	0.086^{a}	8.1^{a}	21.3^{a}	0.58^{ab}
	Second growing season, shoot micronutrient content							
Control	6.2^{a}	9.8^{a}	70.0^{a}	1.3^{b}	0.000^{a}	0.82^{a}	2.4^{a}	0.56^{b}
CM	4.9^{a}	8.2^{ab}	78.0^{a}	1.7^{b}	0.004^{a}	0.83^{a}	2.7^{a}	0.99^{a}
DM	5.9^{a}	7.2^{b}	99.7^{a}	2.3^{a}	0.009^{a}	0.75^{a}	2.2^{a}	0.88^{a}

†Means followed by different letters are significantly different at 0.05 probability level.
‡ nd: Non-detected.

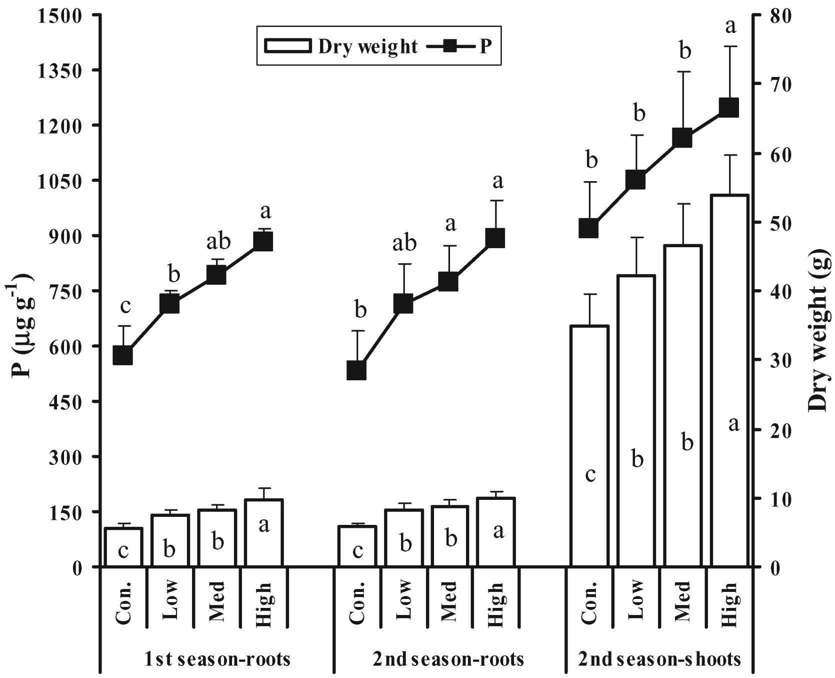

Fig. 4. Plant root and shoot dry weight (g) and P content (μg g^{-1}) for the tested manure application rates and growing seasons.

that animal manure application rates had a significant effect on plant root and shoot growth and attributed it to the increase in nutrients availability and improvement of soil structure. Results of our study concur with the findings reported by Weaver[40] who studied the responses of both root and shoot growth of corn crop under different management practices. The significant increase in plant biomass with increasing manure amendment application rates is a practical indicator of improved quantity of sweet corn and forage produced under organic manure application, resulting in more feed for animals and consequently abundant food for humans.[4,25]

Macronutrient contents

The concentration of P (Fig. 4) and that of Ca and Mg (Fig. 5) in roots increased with increasing rates of manure application during both growing seasons. However, this increase was not statistically significant. Significant differences always occurred between the control and the highest rate of manure application. As a general pattern, the higher concentrations of macronutrient were observed under higher application rate and vice versa. These results are related to the significant correlation between dry weight of roots and their content of macronutrients (Tables 6 and 8).

As noted in root tissues, macronutrient contents in shoot tissues increased with increasing rates of manure application. During the second growing season, macronutrient content data for shoot and root tissues showed a clear trend of greater accumulation of macronutrients in shoot tissue rather than in root tissues. Our results depicting this trend closely agreed with the results of those with Irshad et al.[11] who compared different rates of application of organic and inorganic fertilizers on corn tissue content of P, Ca, and Mg and found a siginificant increase in the nutrient concentration under manure application compared with control treatment.

The effect of rate of manure application on corn root tissue N and C during the first growing season is illustrated in Figure 6. No significant differences were observed between the control and low application rates, and between the medium and high application rates for N concentration. However, there was a significant difference between these two groups for N accumulation in sweet corn roots (Fig. 3). The highest accumulation of N occurred under the highest application rate and the lowest application rates were with control treatments. The C content in plant root tissues increased with increasing rates of manure. The increase of N and C concentration in corn plant root might be related to the positive significant correlation ($r^2 = 0.70$) between N and C concentrations (Table 6). Our results agree with those of He et al.[25] who reported a significant increase in N and C concentration in the roots of two maize (*Zea mays* L.) cultivars with four increasing in N application rate. They also reported a positive significant correlation between N and C in root tissues.

Micronutrient contents

In general, the micronutrients in corn root tissues increased with increasing rates of manure application (Table 9). However, during first growing season, there was no significant effect of application rate on Ni concentration. Dalton et al.[41]

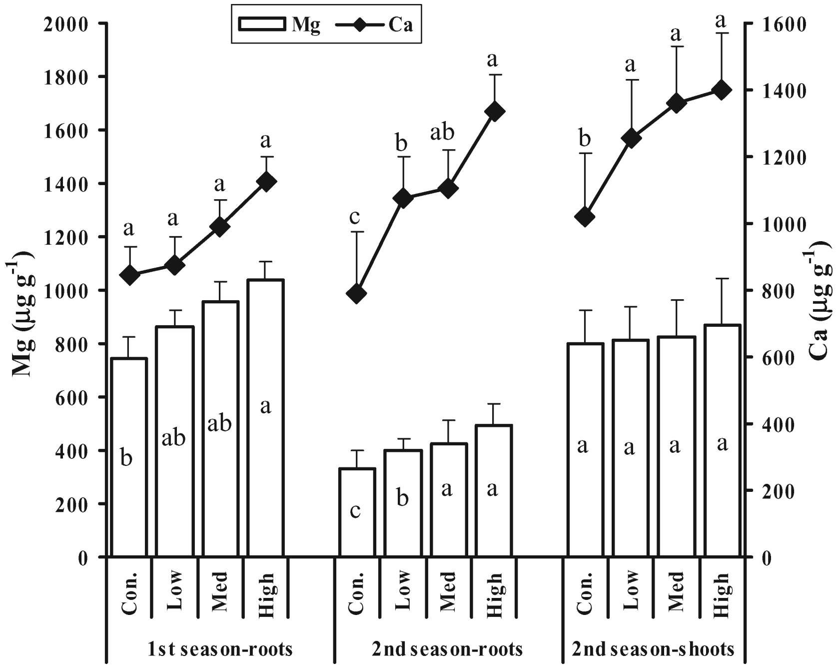

Fig. 5. Plant root and shoot dry weight (g) and Ca, Mg contents (μg g^{-1}) for the tested manure application rates and growing seasons.

reported no evidence of Ni deficiency in the soils under regular plantation. Although the importance of Ni is unknown, most of the plants act as Ni fixing.[42] This may be the reason for the significant presence of Ni in plant root and shoot tissues during second growing season. Both Fe and Cd increased by increasing the application rate, but the values did not reach a significant level.

The micronutrient in this study (except Pb) had higher concentrations in root compared to shoot tissue. The increase in concentration of micronutrients with the increase in application rate might be related to the increase in micronutrients availability in the soil solid phase[11,29] and their usual pathway to the plant system through the surrounding liquid phase, the soil solution and then to the plant root and plant cells.[39]

Effect of number of manure applications

Biomass and macronutrient contents

The effects of the number of manure applications on dry weights of roots, shoots, and on concentrations of macronutrient during the second growing season are presented in Figure 7 and 8. Dry root and shoot weights were significantly higher for two time application treatments (TTA) then for one time application plots (OTA). The biomass increase was substantially greater in shoots

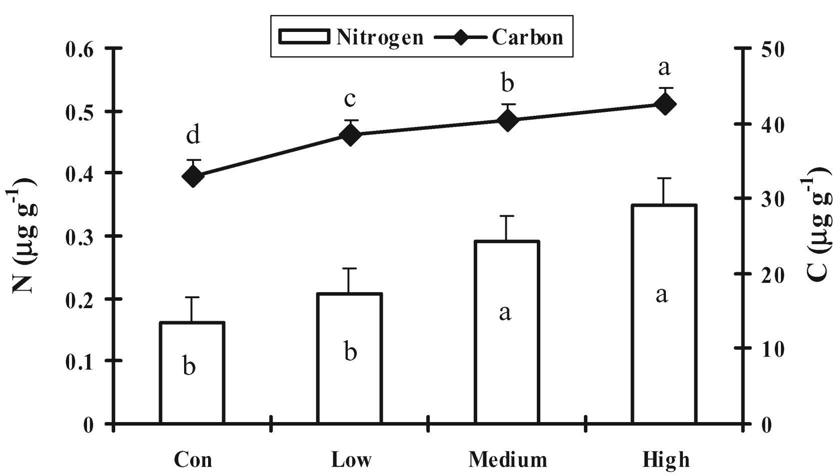

Fig. 6. Plant root and shoot dry weight (g) and N, C content (μg g^{-1}) for the tested manure application rates and first growing seasons.

Table 8. Correlation coefficients for roots and shoots fresh and dry weight, and roots and macro and micronutrients content at the harvest of second growing season.

	P	*Ca*	*Mg*	*Zn*	*Mn*	*Fe*	*Cu*	*Cd*	*Cr*	*Ni*	*Pb*
Root											
Dry	0.56^{**}	0.52^{**}	0.35^{*}	-0.09^{NS}	0.04^{NS}	0.19^{NS}	0.11^{NS}	-0.03^{NS}	0.19^{NS}	0.15^{NS}	0.55^{**}
P		-0.08^{NS}	0.42^{**}	0.31^{*}	0.06^{NS}	0.35^{*}	0.60^{**}	0.18^{NS}	0.31^{*}	0.55^{**}	0.19^{NS}
Ca			0.36^{*}	-0.03^{NS}	0.21^{NS}	0.30^{*}	0.02^{NS}	0.07^{NS}	0.18^{NS}	0.02^{NS}	0.50^{**}
Mg				0.65^{**}	0.38^{**}	0.65^{**}	0.59^{**}	0.57^{**}	0.58^{**}	0.45^{**}	0.28^{NS}
Zn					0.42^{**}	0.66^{**}	0.72^{**}	0.81^{**}	0.63^{**}	0.36^{*}	0.01^{NS}
Mn						0.50^{**}	0.43^{**}	0.56^{**}	0.46^{**}	0.13^{NS}	0.09^{NS}
Fe							0.71^{**}	0.79^{**}	0.75^{**}	0.28^{*}	0.08^{NS}
Cu								0.72^{**}	0.64^{**}	0.47^{**}	0.03^{NS}
Cd									0.74^{**}	0.31^{*}	-0.09^{NS}
Cr										0.41^{**}	0.16^{NS}
Ni											0.08^{NS}
Shoot											
Dry	0.27^{NS}	0.28^{NS}	-0.30^{NS}	-0.34^{*}	-0.26^{NS}	-0.27^{NS}	-0.08^{NS}	0.04^{NS}	-0.12^{NS}	0.59^{**}	0.30^{*}
P		0.11^{NS}	0.23^{NS}	0.24^{NS}	0.12^{NS}	0.15^{NS}	0.52^{**}	0.23^{NS}	0.23^{NS}	0.14^{NS}	0.16^{NS}
Ca			0.09^{NS}	-0.20^{NS}	0.29^{NS}	0.31^{*}	0.25^{NS}	-0.01^{NS}	0.13^{NS}	-0.18^{NS}	-0.03^{NS}
Mg				0.57^{**}	0.45^{**}	0.28^{NS}	0.45^{**}	0.13^{NS}	0.09^{NS}	-0.32^{*}	0.04^{NS}
Zn					0.42^{**}	0.29^{NS}	0.36^{*}	0.23^{NS}	0.22^{NS}	-0.31^{*}	-0.15^{NS}
Mn						0.90^{**}	0.17^{NS}	0.03^{NS}	0.62^{**}	-0.23^{NS}	-0.25^{NS}
Fe							0.12^{NS}	0.01^{NS}	0.70^{**}	-0.32^{*}	0.24^{NS}
Cu								0.08^{NS}	0.19^{NS}	-0.17^{NS}	0.16^{NS}
Cd									0.05^{NS}	-0.10^{NS}	0.01^{NS}
Cr										-0.04^{NS}	-0.03^{NS}
Ni											0.34^{*}

NS, *, ** = Not significant, significant, and highly significant, respectively.

compared to roots. The TTA had higher concentration of P (1.5 times) and Mg (1.5 to 2 times) in roots and that of Ca and Mg in shoots. However, Ca contents in roots did not increase significantly under TTA compared to OTA. The observed results are not only related to the increase in the macronutrients pool within the root zone. It might be related to the differences in nutrient mobility within the corn plant and the flow of more of these nutrients via the

Table 9. Manure rate effect on micro-nutrients concentration in roots and shoots at the harvest of first and second growing seasons.

Rate of application	*First growing season, root micronutrient content ($\mu g\ g^{-1}$)*							
	Zn	*Mn*	*Fe*	*Cu*	*Cd*	*Cr*	*Ni*	*Pb*
Control	$12.7^{c\dagger}$	45.2^{c}	1250^{a}	27.7^{b}	0.05^{a}	10.9^{b}	nd ‡	0.47^{b}
Low	15.9^{b}	61.8^{b}	1374^{a}	28.6^{b}	0.07^{a}	12.0^{b}	nd	0.59^{ab}
Med	18.8^{ab}	68.4^{b}	1491^{a}	35.2^{ab}	0.10^{a}	14.9^{ab}	nd	0.70^{ab}
High	21.8^{a}	87.6^{a}	1765^{a}	41.0^{a}	0.12^{a}	17.4^{a}	nd	0.84^{a}
	Second growing season, root micronutrient content							
Control	9.5^{b}	53.2^{b}	564^{b}	4.5^{c}	0.07^{a}	6.5^{b}	13.7^{b}	0.46^{b}
Low	10.5^{ab}	93.7^{a}	839^{a}	5.4^{bc}	0.07^{a}	6.9^{b}	14.0^{b}	0.46^{b}
Med	10.9^{ab}	76.2^{ab}	968^{a}	6.5^{ab}	0.08^{a}	7.7^{ab}	19.5^{ab}	0.55^{b}
High	12.1^{a}	87.2^{ab}	1038^{a}	7.4^{a}	0.09^{a}	9.5^{a}	22.9^{a}	0.91^{a}
	Second growing season, shoot micronutrient content							
Control	6.2^{a}	9.8^{a}	99.7^{a}	1.31^{b}	0.000^{a}	0.82^{a}	1.85^{b}	0.56^{b}
Low	4.9^{a}	7.1^{a}	61.1^{b}	1.94^{a}	0.005^{a}	0.81^{a}	2.42^{ab}	0.85^{a}
Med	5.3^{a}	7.7^{a}	76.3^{ab}	1.96^{a}	0.007^{a}	0.80^{a}	2.48^{ab}	0.94^{a}
High	6.1^{a}	8.3^{a}	84.4^{ab}	2.23^{a}	0.008^{a}	0.89^{a}	2.92^{a}	1.00^{a}

†Means followed by different letters are significantly different at 0.05 probability level.
‡nd: Nondetected.

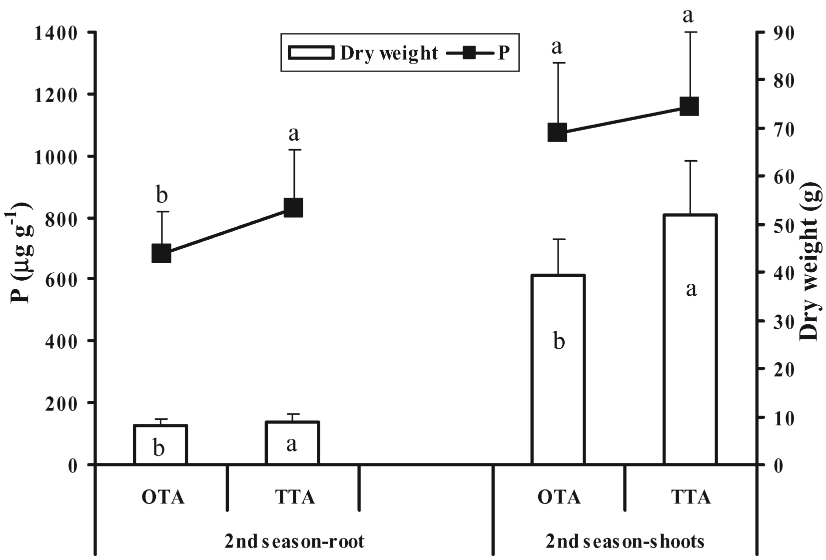

Fig. 7. Means, standard error bars, and Duncan's test letters of the effect of number of application on root and shoot dry weight (g) and P content (μg g^{-1}) for the harvest of plant tissues during second growing season.

roots.[39,43] The high level of organic amendment in the TTA led to improved soil fertility and quantity of sweet corn produced under organic amendment by increase biomass production and its content of macro nutrient. These findings concur with those reported by Valenzuela et at. and Kumar et al.[4,25]

Micronutrient contents

Micronutrient contents in roots and shoots tissues grown in TTA soils amendments were greater than those in OTA treatments, with the exceptions of Ni and Pb in roots and Cd and Cr in shoots (Table 10). The additional amount of applied manures during TTA and the resultant decomposition might have caused an increase in [micronutrients] availability of in soils in TTA treatments as compared to OTA. Our results concur with the findings of Lipoth and Schoenau[18] who reported an increase in the accumulation of micronutrients (Cu, Zn and Cd) in wheat plants under repeated applications of different manure amendments over a period of 5 years.

Correlation matrices

Table 6 illustrates the correlations matrix for the first growing season variables. There were very strong correlations

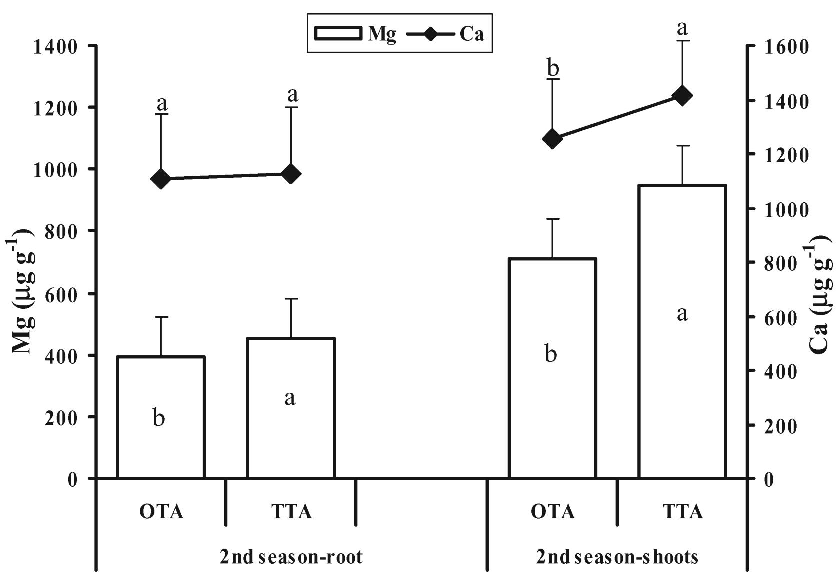

Fig. 8. Means, standard error bars, and Duncan's test letters of the effect of number of application on root and shoot Ca and Mg content (μg g^{-1}) at the harvest of plant tissues during second growing season.

Table 10. Number of manure application effect on micronutrients concentration in roots and shoots at the harvest of second growing season.

No. of application	*Root micronutrient content ($\mu g\ g^{-1}$)*							
	Zn	*Mn*	*Fe*	*Cu*	*Cd*	*Cr*	*Ni*	*Pb*
OTA	$8.2^{b\dagger}$	56^{b}	586^{b}	4.2^{b}	0.02^{b}	6.2^{b}	16.7^{a}	0.57^{a}
TTA	13.3^{a}	105^{a}	1200^{a}	8.2^{a}	0.13^{a}	9.4^{a}	19.5^{a}	0.65^{a}
	Shoot micronutrient content							
OTA	3.8^{b}	6.9^{b}	59.6^{b}	1.6^{b}	0.005^{a}	0.7^{a}	1.4^{b}	0.79^{b}
TTA	7.3^{a}	9.1^{a}	95.6^{a}	2.3^{a}	0.007^{a}	0.9^{a}	3.4^{a}	0.97^{a}

†Means followed by different letters are significantly different at 0.05 probability level.

especially between root dry weight and macro N, C, P, Zn, Mn, Cr, and Pb. A highly significant ($P < 0.01$) positive correlation was also found between N and C content in roots. There was a significant positive correlation between the macronutrients except for N, Ca and Mg. The root dry weight had significant ($P < 0.05$) positive correlations with Ca, Mg, Fe, and Cd. Also, macronutrients (N, C, P, Ca and Mg) had significant positive correlation with Zn (except Mg), Mn, Cd (except Ca and Mg), and Cr. There was no significant correlation of micronutrients with Cd and Pb (except Cr). Iron had a highly significant correlation with Mn but not with Zn, Cu, Cd, or Pb.

For the second growing season, dry weight of roots was significantly ($P < 0.05$) correlated with all the macronutrients and with only Pb among micronutrients. Results also showed a correlation of P and Ca with Mg but no correlation between P and Ca. There was a low correlation between P and Ca with micronutrients and a strong correlation of Mg with micronutrients except Pb. A strong significant correlation was found between micronutrients in roots except with Pb, which had no correlation with other micronutrients. For shoots, there was a weak correlation between all the measured components, the correlation coefficients did not reach a significant level, yet there was a highly significant correlation between shoots dry weight and Ni concentration ($r^2 = 0.59$), and between Mg and Zn ($r^2 = 0.57$) and Cu ($r^2 = 0.45$), Mn and Mg ($r^2 = 0.45$) and Zn ($r^2 = 0.42$), and Mn and Fe ($r^2 = 0.90$). Some of these results were comparable with previously reported studies by Walker and Peck[44] which showed significant correlation between macronutrient contents in corn plants. He et al.[28] also reported a positive significant correlation between N and C in plant roots.

Conclusions

Results for the effect of manure types, rates, and number of applications, on sweet corn root and shoot biomass and macro- and micro-nutrient contents showed that chicken manures performed better than dairy manure although these manures were applied based on equivalent N weight. Concentrations of N and C in sweet corn roots for manure were greater than control treatment with no significant difference between the concentrations in CM and DM treatments. Major macronutrient (e.g., P, Ca, and Mg) contents in roots and shoots were higher for CM than for DM and control treatments. Overall, results of this study supported the performance of animal manures with respect to sweet corn production in the following order: CM > DM > Control. Therefore CM could be used successfully as a soil amendment for corn crop.

In general, the biomass production and nutrient content of roots and shoots of sweet corn continued to increase with increase in manure application rates from 0 to 672 kg N ha^{-1}. The dry weight of sweet corn shoots and roots during the second growing season increased from 35 to 53.7 g and 3.7 to 7.9 g, respectively for above two rates. The number of manure applications had a significant effect on root and shoot biomass and macro- and micronutrient concentration in the plant roots and shoots. Despite the positive effects of moderate animal manure amendments in enhancing levels of macro- and micro-nutrients in sweet corn plant tissues, high nutrient contents may reach toxicity levels and might pose health risks to human and animals who feed on these plant materials. In addition, antibiotics/pharmaceuticals present in these manures might be taken up by sweet corn and accumulate in their plant tissues which might negatively impact human and animal health if used for food or feed. There was a strong, positive correlation between root biomass and macronutrient contents. However, there was a weak correlation between the shoot dry biomass and the concentrations of both macro- and micro-nutrients.

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